OBSCURED AND UNOBSCURED AGN EVOLUTION AND THE X-RAY BACKGROUND

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Abstract

The Great Observatories Origins Deep Survey (GOODS) combines deep HST and Spitzer imaging with the deepest Chandra/XMM observations to probe obscured AGN at higher redshifts than previous multiwavelength surveys. We present a self-consistent implementation of the AGN unification paradigm, which postulates obscured AGN wherever there are unobscured AGN, to successfully explain the infrared, optical, and X-ray number counts of X-ray sources detected in the GOODS fields. Assuming either a constant ratio of obscured to unobscured AGN of 3:1 (the local value), or a ratio that decreases with luminosity, and including Compton-thick sources, we can explain the spectral shape and normalization of the extragalactic X-ray "background" as a superposition of unresolved AGN, predominantly at z~0.5-1.5 and $L_x \sim 10^{43}$-10^{44} ergs/s. The possible dependence of the obscured to unobscured ratio with redshift is not well constrained; present data allow it to decrease or increase substantially beyond z~1.

Method

The two main ingredients used to predict the AGN number counts and contribution to the X-ray background are: (*i*)The AGN luminosity function and its evolution. We used the luminosity function of Ueda et al. (2003), which is based on hard X-ray observations and thus relatively free of bias against obscured AGN. (*ii*) The AGN SED, in terms of intrinsic luminosity and neutral hydrogen column density (N_H) along the line of sight. We assumed an underlying power-law X-ray spectrum (E>0.5 keV) with photon index of Γ 1.9, typical of unobscured AGN. In the optical (λ=0.1-1 microns), we used the Sloan Digital Sky Survey Composite Quasar Spectrum (Vanden Berk et al., 2001) plus Milky-Way-type reddening laws and a standard dust-to-gas ratio to convert N_H to A_V. An L* elliptical host galaxy was then added to the resulting optical spectrum. In the infrared (λ >1 micron) we used dust emission models by Nenkova et al. (2002) with the corresponding conversion from N_H value to viewing angle. AGN models with the same intrinsic luminosities were normalized at 100 microns. The standard X-ray to optical luminosity ratio was used to fix the scale of the different models.

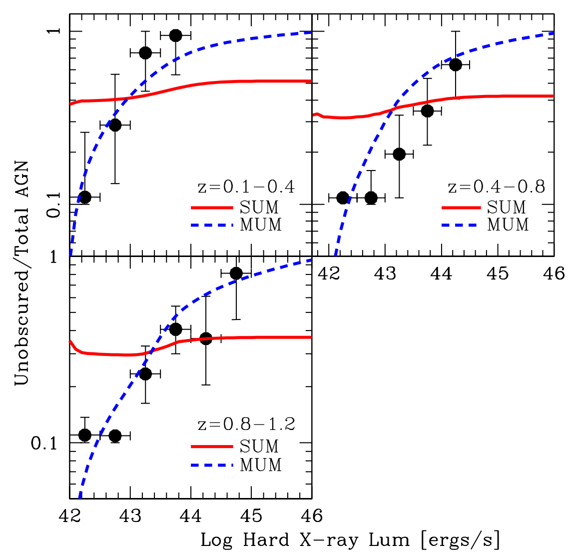

Figure 1. Unobscured AGN ratio as a function of hard X-ray luminosity. Filled circles: data from Barger et al. (2005) combined with our sample. (Solid lines:) Ratio predicted by our simple unified model. The discrepancy between predictions and observations is very clear. In this redshift range, the discrepancy cannot be attributed to selection effects since the observed sample is mostly complete both for obscured and unobscured AGN. Therefore, we also used a modified unified model (Dashed lines) in which the obscured-to-unobscured AGN ratio decreases linearly with luminosity.

Summary

Using the simplest AGN unification model we have explained the spectral shape and intensity of the X-ray background. This is the first demonstration that a model assuming a constant ratio of obscured to unobscured AGN, independent of redshift or luminosity, can simultaneously explain the observed X-ray background and the optical and X-ray counts of AGN detected in deep X-ray surveys (Treister et al., 2004). At the same time, a model that incorporates a changing ratio with luminosity, as suggested by recently available observations (Fig. 1), can also successfully explain the X-ray background proper-

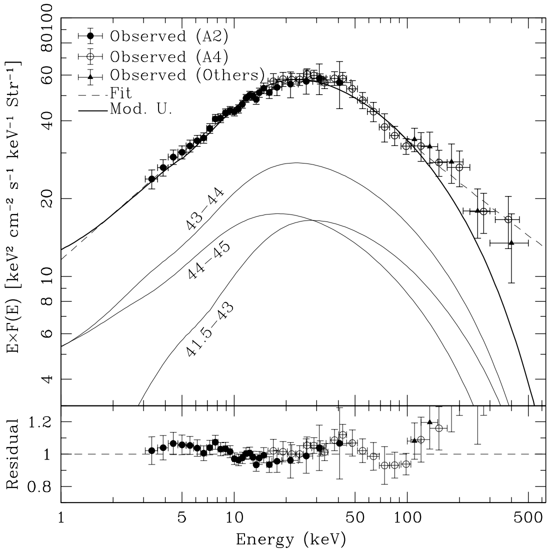

Figure 2. X-ray background population synthesis for an AGN unification model in which the fraction of obscured AGN decreases with increasing luminosity (solid line). The agreement with observations (data points, dashed line) is very good, with a reduced ξ^2 of 0.648. Labeled solid lines show the contribution from sources in different X-ray luminosity bins. The maximum contribution to the X-ray background comes from sources with log LX=43-44, that is, moderate luminosity AGN.

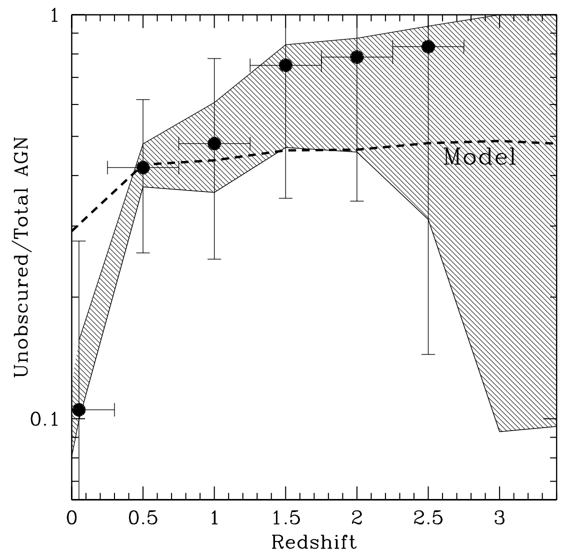

Figure 3. Ratio of unobscured-to-total AGN as a function of redshift. Circles: Observed data points from a sample compiled from several X-ray surveys for which the total spectroscopic completeness level is 66%. Thin solid lines: effects of adding the unidentified sources to each bin, weighting by the comoving volume on each redshift bin, assuming that all the unidentified sources are obscured (lower line) or unobscured (upper line) AGN. Dashed line: Predicted ratio as a function of redshift for a unified model in which the ratio (geometry) depends only on luminosity, not redshift. That the data points lie systematically above our model is not unexpected, since obscured AGN are preferentially missed. The significant incompleteness at $z > 1.5$ makes it impossible, given the current data, to rule out a constant ratio with redshift.

ties (Treister & Urry, 2005), as shown in Fig. 2.

The integral constraint of the X-ray background clearly does not provide a sensitive probe of the fraction of the obscured AGN; other observations, in particular a high-flux X-ray sample ($\gtrsim 10^{-14}$ erg cm^{-2} s^{-1}) with a very high spectroscopic completeness level (>90%), is needed to test whether the ratio depends on redshift, i.e., whether the evolution of obscured and unobscured AGN is different. As shown in Fig. 3, unification by orientation — in which obscured and unobscured AGN have the same evolution — is consistent with the data. In order to obtain this highly complete sample, accurate redshifts for sources with optical magnitudes $24 \lesssim R \lesssim 27$ are needed. This is impossible with current state-of-the-art 8m-class telescopes. However, good photometric redshifts using medium-band filters down to these magnitudes are possible and will allow to solve the redshift dependence problem.

The resolved fraction of the X-ray background is $\lesssim 50\%$ in the 7-10 keV band and decreases with increasing energy. If the unification model presented here is correct, ~ 50% of AGN are currently missed by deep *Chandra* or *XMM* surveys. These are very obscured AGN that will be detected only by hard X-ray observatories, like the Black Hole Finder probe, at X-ray energies where the effects of dust obscuration are negligible. These surveys will detect a large fraction of the most obscured AGN, providing for the first time an unbiased census of the black hole activity in the Universe.

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